UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A211 955

DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

DTIC FILE COPY

DTIC ELECTE AUG 28 1989 S D D

1b. RESTRICTIVE MARKINGS NONE	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE Not Applicable	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) Same
6a. NAME OF PERFORMING ORGANIZATION Defense Mapping Agency Systems Center; 6b. OFFICE SYMBOL (If applicable) EG	7a. NAME OF MONITORING ORGANIZATION Same
6c. ADDRESS (City, State, and ZIP Code) 12100 Sunset Hills Road Reston, Virginia 22090-3207	7b. ADDRESS (City, State, and ZIP Code) Same
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Not Applicable; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Not Applicable
8c. ADDRESS (City, State, and ZIP Code) Not Applicable	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. N/A; PROJECT NO. N/A; TASK NO. N/A; WORK UNIT ACCESSION NO. N/A

11. TITLE (Include Security Classification)
Geodetic Point Positioning with GPS Carrier Beat Phase Data from the CASA UNO Experiment (unclassified)

12. PERSONAL AUTHOR(S)
Malys, Stephen and Jensen, Peter

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical	FROM N/A TO N/A	1989, August 1	

16. SUPPLEMENTARY NOTATION
Prepared for submission to the Journal: Geophysical Research Letters, (CASA UNO issue)

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Geodesy, ~~GPS~~, Point Positioning, Satellite Geodesy. ~~WGS 84~~ JES

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Abstract. The Global Positioning System (GPS) carrier beat phase data collected by the TI4100 GPS receiver has been successfully utilized by the US Defense Mapping Agency in an algorithm which is designed to estimate individual absolute geodetic point positions from data collected over a few hours. The algorithm uses differenced data from one station and two to four GPS satellites at a series of epochs separated by 30 second intervals. The 'precise' GPS ephemerides and satellite clock states, held fixed in the estimation process, are those estimated by the Naval Surface Warfare Center (NSWC). Broadcast ephemerides and clock states are also utilized for comparative purposes.

An outline of the applied data corrections, the mathematical model and the estimation algorithm are presented. Point positioning results and statistics are presented for a globally-distributed set of stations which contributed to the CASA UNO experiment. Statistical assessment of 114 GPS-realized point positions at 11 CASA UNO stations indicates that the overall precision of a point position component, estimated from a few hours of data, is 73 centimeters. Solution of the long line geodetic inverse problem using repeated results such as these offers a new tool for those studying geodynamics on a global scale.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Stephen Malys	22b. TELEPHONE (Include Area Code) (202) 227 2154; 22c. OFFICE SYMBOL DMASC/EG

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

89 8 29 083

GEODETIC POINT POSITIONING WITH GPS CARRIER BEAT PHASE DATA FROM THE CASA UNO EXPERIMENT

Stephen Malys and Major Peter A. Jensen[1]

United States Defense Mapping Agency

Abstract. The Global Positioning System (GPS) carrier beat phase data collected by the TI4100 GPS receiver has been successfully utilized by the US Defense Mapping Agency in an algorithm which is designed to estimate individual absolute geodetic point positions from data collected over a few hours. The algorithm uses differenced data from one station and two to four GPS satellites at a series of epochs separated by 30 second intervals. The 'precise' GPS ephemerides and satellite clock states, held fixed in the estimation process, are those estimated by the Naval Surface Warfare Center (NSWC). Broadcast ephemerides and clock states are also utilized for comparative purposes.

An outline of the applied data corrections, the mathematical model and the estimation algorithm are presented. Point positioning results and statistics are presented for a globally-distributed set of stations which contributed to the CASA UNO experiment. Statistical assessment of 114 GPS point positions at 11 CASA UNO stations indicates that the overall precision of a point position component, estimated from a few hours of data, is 73 centimeters. Solution of the long line geodetic inverse problem using repeated point positions such as these can potentially offer a new tool for those studying geodynamics on a global scale.

Introduction

The Defense Mapping Agency (DMA) has been developing a geodetic point positioning algorithm which is designed to estimate individual geodetic point positions from data collected with a TI4100 geodetic GPS receiver. Descriptions of the pseudorange and carrier beat phase data which this receiver collects can be found in Goad [1985].

The DMA point positioning algorithm has been introduced in Malys and Ortiz [1989]. The preprocessing and position estimation software packages which mechanize this algorithm are known respectively as STARPREP and GASP. STARPREP is a contraction for geoSTAR PREProcessor while GASP is an acronym for Geodetic Absolute Sequential Positioning program.

As a participant in the CASA UNO experiment, DMA acquired a subset of the available CASA UNO TI4100 tracking data. The authors selected a subset which would aid in evaluating and enhancing the developing algorithm. In particular, a set of globally-distributed CASA UNO stations which contributed data over the longest series of days were selected. One of the primary goals of this study was to demonstrate a world-wide ability to estimate geodetic-quality point positions from the current (Block I) GPS constellation. Statistical analysis of positioning results over the series of quasi-independent data sets is used as a tool in evaluating the precision of any individual position estimate. A limited assessment of accuracy is also possible for some stations.

Since the introduction of this positioning algorithm in Malys and Ortiz [ibid.], a number of important algorithmic improvements have been made which contributed to significant improvements in the precision of position estimates. These improvements will be described in the sections which follow.

[1] Royal Australian Survey Corps

Data Preprocessing

Before the TI4100 carrier beat phase data is used to estimate point positions, the 'raw' data is corrected for a series of quantifiable errors. The corrections are listed in Table 1 along with their functional dependencies. With one exception, the formulation for the computation of these data corrections can be found in Malys and Ortiz [op cit.]. The ionospheric correction to the carrier beat phase data has been revised to account for the initial integer cycle ambiguities on the L_1 and L_2 channels for each satellite being tracked. After the receiver's frequency offsets are accounted for, the initial integer is subtracted from all subsequent data values until a discontinuity in the ionospheric correction is detected. When a discontinuity is detected, it is attributed to a loss of lock (cycle slip) on one of the channels and a new 'initial' integer is stored and subtracted from subsequent data values. Moreover, when a discontinuity is detected, the receiver frequency offset correction is applied such that the first data epoch after the discontinuity is used as a reference epoch until another discontinuity is detected. Since the GASP algorithm is tolerant of occasional losses of lock and data gaps, there is no attempt made at repairing cycle slips.

Concurrent with the computation and application of the time tag and data corrections shown in Table 1, the preprocessor interpolates and stores the satellite ephemerides and clock states for the data span of interest. Either broadcast or NSWC precise ephemerides and clocks can be utilized. The broadcast ephemerides are obtained from predicted orbital elements, found in block number 9 in the FICA file format [ARL, 1987]. These elements are converted to Earth-centered, Earth-fixed state vectors by using the algorithm of Van Dierendonck et al.[1980]. The broadcast satellite clock corrections are used only if the broadcast ephemerides are adopted.

The NSWC precise ephemerides (state vectors at 15 minute intervals) and clock state estimates (at 1 hour intervals) are generated on a weekly basis from smoothed pseudorange data collected at ten globally distributed tracking sites operated by the US Air Force (5) and DMA, in cooperation with other nation agencies (5). The GPS orbit/clock determination algorithm used at NSWC has been described by Swift [1985, 1987]. An assessment of the weekly NSWC precise GPS ephemerides and clock states has been presented by Gouldman et al. [1989]. The fixed, ten station tracking network has been analyzed by Malys [1988b] and Swift [1989]. The STARPREP preprocessor uses an eight-point Lagrange interpolation method to obtain precise satellite position vectors and satellite clock offsets at the observation epochs (transmission epochs). All GPS-related algorithms in use at DMA and NSWC utilize a consistent set of geodetic models and constants defined by the World Geodetic System 1984 (WGS 84) [DMA,1987].

While the use of precise (post-fit) ephemerides and satellite clock estimates is preferred for geodetic applications, the authors purposely retained the ability to utilize the broadcast (predicted) information for possible adaptation of this positioning algorithm to use in the field, where post-fit ephemerides and clock states are not available. Moreover, the use of broadcast information facilitates a wide range of analyses regarding satellite performance and quality of the broadcast data.

Modeling and Estimation

The corrected carrier beat phase data is known to contain biases, integer cycle ambiguities and other undesirable characteristics which are dependent on factors such as initial acquisition epoch, cycle slips and receiver frequency standard fluctuations. Moreover, common errors may be inadvertently introduced through the application of less than perfect data corrections such as those associated with the atmosphere, and less than perfect estimates of the satellite ephemerides and clock states. In an attempt to remove these undesirable contributions, the GASP algorithm is designed around a differencing scheme which cancels common errors in the corrected data and adopted satellite ephemerides and clock states.

The first step in forming an observable is to difference two consecutive carrier beat phase observations (converted to kilometers) of the same satellite. For all data sets analyzed for this study, the interval between consecutive observations is 30 seconds. This between-epoch difference (a biased delta-range) is then differenced with a corresponding between-epoch difference from another satellite. One 'GASP observable' is formed from data collected at one station from two satellites at two consecutive epochs. Since the TI4100 receiver tracks up to four satellites simultaneously, a given pair of data epochs can yield up to three 'GASP observables'. A graphic representation of this differencing scheme is given in Malys and Ortiz [op.cit.]. For each pair of data epochs utilized, one satellite is used as the reference from which the others are differenced. An important algorithmic improvement, implemented since the writing of Malys and Ortiz [op cit.], involves the selection of the reference satellite. Previously, the choice of this reference did not change through a data span unless it (the lowest PRN number allowed through the preprocessor), became unavailable. For all the point positions estimated in this study, the choice of the reference satellite is sequential, such that for every new pair of epochs processed, the next higher available PRN number is used as the reference in the differencing scheme. The choice cycles back to the lowest available PRN number after the list of tracked satellites has been exhausted.

Before adopting this sequential reference satellite selection process, the authors tested the concept that the satellite with the most stable clock should be used as the reference throughout the data span. Comparison of statistics from repeated estimates however, indicated that the sequential approach offered many more benefits. One can rationalize these benefits in terms of reduced correlation among the observables. The implementation of this sequential reference satellite selection process improved day to day repeatability, the RMS of residuals (for most fits), and the variance-covariance and correlation matrices of the estimated parameters by up to 30%. In particular, the GASP-estimated longitudinal component reaped almost all of the b[illegible]

After forming an array of GASP observa[illegible] least squares estimation technique is applied such that the ve[illegible]or of estimated parameters contains an 'alteration' to the a priori Earth-centered, Earth-fixed Cartesian station antenna position components. No other parameters are estimated. After three iterations of the non-linear model, the estimated parameters, their scaled variance-covariance matrix and the RMS of residuals are passed to a sequential estimation algorithm. This sequential technique (a Kalman filter) utilizes the RMS of residuals from the least squares fit as the variance of a GASP observable. In the sequential estimation technique, a parameter update is performed after each observable is processed. This allows plots to be generated which show the position component estimates as a function of the data set span. The level of convergence in the plots is one indication of the precision of the position estimate. Analysis of residual plots and of a posteriori variance-covariance matrices are also helpful in evaluating an individual result.

Other recent algorithmic improvements include the replacement of the sequential estimation module and redefining the level of process noise associated with the vector of estimated parameters. For the results reported in this study, a process noise of 1 cm^2 was assigned to each estimated position component.

Point Positioning Results

While the CASA UNO experiment focused on the Central and South American region, an extended (world-wide) fiducial network of tracking stations was necessary for improved orbit determination and orbit 'relaxation' by relative positioning algorithms. The globally distributed set of stations which contributed to the experiment provided an opportunity to evaluate the STARPREP and GASP software packages over a variety of geometries and tracking span scenarios. The stations which contributed data over a long series of days were especially valuable since a set of quasi-independent position estimates can be generated for such stations. The authors choose to label these estimates 'quasi-independent' because the daily tracking geometries are usually very similar at any given station. Table 2 summarizes the CASA UNO data sets which the authors selected for point positioning. Note that there is no need for simultaneous observation from any two stations since each point position is estimated individually.

In all but a few cases, PRN number 8 was purposely excluded from processing since it operated on a quartz crystal oscillator. Experience with the GASP algorithm has demonstrated a degradation of positioning results when a satellite crystal oscillator is allowed to contribute data. If however, PRN 8 creates a particularly favorable geometric situation, it can strengthen the estimation process.

The mean WGS 84 geodetic coordinates estimated for the selected set of CASA UNO stations are presented in Table 3. While these means were obtained from varying numbers of data sets and tracking geometries, the standard deviations shown in Table 4 indicate that the separate position estimates are all of comparable precision. Note that the standard deviations in Table 4 represent the dispersion of an individual position component estimate, estimated from a single 4 to 6 hour data set. These standard deviations were obtained from the sample population of GASP positioning results. The GASP-generated standard deviations from any particular position estimate are in close agreement with the values shown in Table 4. All results given in Tables 3 and 4 were generated through the adoption of the NSWC WGS 84 precise satellite ephemerides and clock states. These ephemerides and satellite clock states are held fixed in the GASP algorithm. Common errors in the interpolated satellite position vectors and clock state estimates difference away in the construction of the GASP observables.

The mean value of the standard deviations listed in Table 4 (Cartesian or geodetic) is 73 centimeters. This mean value, obtained from 114 quasi-independent point positions at 11 CASA UNO stations, can be interpreted as an overall measure of positioning performance under a spectrum of field conditions and tracking geometries. The mean point positions, obtained by averaging the individual estimates for a given station are, of course, significantly more precise than any individual estimate. For example, the mean position components listed in Table 3 have an overall standard deviation of 25 cm.

Since the point positioning algorithm addressed here has potential in-field applications, the authors analyzed its performance in the case where the broadcast satellite ephemerides and clock state predictions were adopted in place of the NSWC precise estimates. Table 5 allows a comparison of point positioning results generated in these two ways. The similarity in these two sets of repeatabilities indicates that the GASP-generated broadcast point positioning results are geodetically useful for field applications. Perhaps most importantly, in-field execution of the STARPREP and GASP software would allow an assessment of a data set's usefulness through analysis of the variance-covariance matrices and plots which GASP produces. If for example, there is any particular position component which is weak or highly correlated with another component, the field operator could possibly eliminate the deficiency before leaving a remote site by re-tracking with an altered scenario.

In addition to larger dispersions in the point positions obtained with the broadcast information, these point positions exhibit biases with respect to the corresponding results generated by adopting the precise ephemerides and clocks states. For example, the broadcast-derived mean ellipsoid height component at the Albrook station is 1.7 meters lower than the corresponding height component generated from the precise ephemerides and clock states. The source and systematic quantification of these biases remain to be explored.

In order to partially assess the accuracy of GASP absolute point positions, the GASP results at five CASA UNO stations were compared to positioning results generated from a collection of independent sources. Table 6 allows a comparison of the mean GASP-estimated positions with absolute positions obtained from three independent methods: TRANSIT (Doppler, NNSS) point positioning, NGS CIGNET station coordinates, and NSWC GPS point positioning. The TRANSIT point positions were estimated by DMA from 64 NAVSAT passes, collected during the CASA UNO campaign (days 20-32). The NGS CIGNET coordinates for the Onsala and Wettzell stations were provided to the authors by Nussear and Chin [personal communication, 1989]. The NSWC point positions were provided, as part of a comprehensive interagency test plan, by Hermann [personal communication ,1989]. Like the GASP mean positions, these NSWC positions are obtained by averaging the set of daily estimates derived from CASA UNO data sets. Hermann's GPS point positioning algorithm is a research-oriented, combination least-squares / sequential filter which uses undifferenced smoothed pseudoranges as observables. A description of this algorithm is given in Hermann [1988]. Note that the Hermann algorithm solves for the receiver's clock state while GASP differences the receiver clock away when the observables are formed.

The accuracy assessments given in Table 6 are limited in the sense that they each involve the mean GASP point position, obtained from the collection of data sets for each station listed. Any individual (daily) GASP position could wander from the mean by an amount commensurate with the standard deviations shown in Table 4. Moreover, the biases shown in Table 6 do not necessarily represent a deficiency in the GASP point position estimates. Each of the independent position estimates used in the comparison (TRANSIT, CIGNET and NSWC) undoubtedly contain errors of their own. Unquantified reference frame differences also contribute to the biases shown in Table 6. Nevertheless, initial comparisons such as these confirm the geodetic utility of the GASP point positioning algorithm.

A comprehensive investigation of the relationships between realizations of GPS precise, GPS broadcast and TRANSIT precise WGS 84 reference frames is being pursued by the authors, using a slowly growing set of globally-distributed, colocated stations. The general problem of relating two satellite-realized reference frames has been treated in Malys [1988].

The Geodetic Inverse Problem

Once a pair of near-simultaneous (in the same GPS week) point positions have been estimated, the long-line geodetic inverse problem can be solved for geodesic distance (on the ellipsoid) and geodetic azimuth between the two stations. Of course, the baseline vector between the two stations can also be obtained by differencing the Cartesian point position components.

Since these methods do not suffer degradation with increased inter-station distances, repeated solutions of the inverse problem can potentially offer new, all-weather tools to those studying global geodynamics. To demonstrate these tools, the authors used the daily GASP point positions described here to solve the geodetic inverse problem for two pairs of stations: Cocos to Limon (geodesic distance = 659 km) and Canberra to Albrook (geodesic distance 14305 km). For the 'short' geodesic, the standard deviations in geodesic distance and geodetic azimuth, over 9 'daily' positions, were 38 cm (0.57 ppm) and 0.33 arc seconds respectively. The very long baseline, over 15 daily positions, achieved standard deviations of 69 cm (0.05ppm) in geodesic distance and 0.04 arc seconds in geodetic azimuth. The standard deviations of the daily inter-station vector lengths were 38 cm and 124 cm for the short and very long baselines respectively.

Concurrent with the solution of the geodetic inverse problem with a series of repeated GASP point positions, the mean geodesic distances and geodetic azimuths between the two pairs of stations were computed. The standard deviations of these means indicate that the mean geodesic distances between Cocos and Limon (9 common tracking days) has been estimated with a precision of 13 cm (0.19 ppm). The mean geodesic distance between Canberra and Albrook (15 common tracking days) has been estimated with a precision of 18 cm (0.01 ppm). The mean geodetic azimuths have standard deviations of 0.11 and 0.01 arc seconds respectively. The global nature of mean geodesics such as these may open a range of possible geodynamic study which has, to this point, been restricted to those utilizing less-mobile satellite laser ranging techniques. When the full GPS constellation is in place, the volume of data now collected in 15 days, will require only about three days to collect.

Summary and Conclusions

The CASA UNO experiment provided an opportunity to demonstrate the abilities of the STARPREP/GASP GPS point positioning algorithm. Statistical assessment of repeated position estimates indicates that geodetic-quality (sub-meter precision) point positions can be obtained on a world-wide basis from GPS TI4100 data collected over a period of a few hours.

There is no doubt that the consistently-generated NSWC precise ephemerides and clock estimates contribute to the success of the point positioning algorithm described here. The continuously operated, ten station / fixed-site GPS tracking network, contributing to the precise ephemeris and clock estimates, is unparalleled in the geodetic community. This asset, along with the mature orbit and clock determination algorithm (OMNIS) developed by NSWC, will continue to be a valuable resource to geodesists using GPS. Note that DMA sponsored the development of OMNIS and is in the process of transitioning the weekly production of precise GPS ephemerides and clock states to the DMAHTC facility in mid-1989.

Despite the abilities and achievements of GPS relative positioning algorithms, geodetic point positioning will continue to be necessary for activities such as mapping control and the estimation of transformation parameters between a World Geodetic System and a local or regional geodetic datum. Relative positioning has limited application in these areas since the 'fixed' end of the baseline, which must be well-known in advance, predominantly defines the reference frame of the floating end of the baseline. For remote areas, where 'fiducial' stations have not been established, geodetic point positioning will be required to fix one end of a new baseline. The logistical requirements of relative positioning surveys (multiple receivers observing simultaneously) also make the point positioning method attractive for many geodetic applications.

Solution of the geodetic inverse problem using repeated GPS point positions may soon offer a new tool to those studying geodynamics on a global scale. Unlike relative positioning algorithms, the quality of the inverse solution (baseline) does not degrade with geodesic length. A 14305 kilometer geodesic, such as that demonstrated here (Canberra Australia to Albrook Panama), can be estimated from 15 repeated, near-simultaneous data sets with a precision of 18 centimeters (0.01 PPM). The orientation of this mean geodesic has been computed with a precision of 0.01 arc seconds. As the authors expect to continue refining the DMA point positioning methodology, and as the growing GPS constellation creates more favorable tracking geometries, the STARPREP/GASP algorithm will succeed beyond the levels of positioning precision and accuracy demonstrated here. In particular, a station's position with respect to the center of mass of the earth can now be measured (by GASP) at the level of several decimeters. Model refinement and optimized geometry will continue to reduce this dispersion. As an example of model refinement, the authors intend to introduce a stochastic zenith tropospheric delay parameter in the estimation process. In the mean time, GPS point positioning will serve as a more than adequate replacement for TRANSIT point positioning. As most readers are aware, the TRANSIT constellation is scheduled to loose operational support in the 1990's. The observation period for GPS point positioning is at least six times shorter than that for NNSS point positioning.

Acknowledgments. We wish to express our gratitude to our past and present colleagues at The Defense Mapping Agency who contributed to the development of the algorithms and software described in this study. Most notably, these include John Bangert, Barbara Denoyer, Brett Merritt, Theodore Meyer, Maria Ortiz, James Slater, and Denise Stutzman. Moreover, we appreciate the cooperation of our colleagues at the Naval Surface Warfare Center, the National Geodetic Survey, the Jet Propulsion Laboratory and all the CASA UNO participants who made the experiment a resounding success.

References

ARL, UT (Applied Research Laboratory, University of Texas at Austin), FIC File Document, Preliminary Version, August 21, 1987.

DMA Technical Report, Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems, DMATR 8350.2, Sept. 1987, Supplement Parts I and II, Dec. 1987.

Goad, C. (ed.), Proc. First Intl. Symp. on Precise Positioning with the Global Positioning System, Rockville, Maryland, April 1985.

Gouldman, M.W., Hermann, B.R.,and Weedon, D.L., Evaluation of GPS Production Ephemeris and Clock Quality, Proc. Fifth Intl. Symp. on Satellite Positioning, Las Cruces, NM, March 1989.

Hermann, B.R.(a), Absolute Positioning Results From The Global Positioning System, NSWC Internal Report, January 1988.

Malys, S.(a), Dispersion and Correlation Among Transformation Parameters Relating Two Satellite Reference Frames, OSU Dept. of Geodetic Science, Report No. 392, Columbus, Ohio, July, 1988.

Malys, S.(b), Similarity Transformation Between NAVSAT and GPS Reference Frames, paper presented at AGU Chapman Conf. on GPS Measurements for Geodynamics, Ft. Lauderdale, Sept. 19-22, 1988.

Malys, S., and Ortiz, M.J., Geodetic Absolute Positioning With Differenced GPS Carrier Beat Phase Data, Proc. Fifth Intl. Symp. on Satellite Positioning, Las Cruces, NM, March 1989.

Swift, E., NSWC's GPS Orbit / Clock Determination System, Proc. First Intl. Symp. on Precise Positioning with the Global Positioning System, Rockville, MD, 1985.

Swift, E.(a), Mathematical Description of the GPS Multi-Satellite Filter / Smoother, Naval Surface Warfare Center, TR 87-187, October, 1987.

Swift, E., Determination of GPS-Realized WGS 84 Station Heights for the Combined Air Force and DMA Tracking Networks, Proc. Fifth Intl Symp. on Satellite Positioning, Las Cruces, NM, March 1989.

Van Dierendonck, A.J.,Russel, S.S., Kopitzke,E.R., and Birnbaum, M.,The GPS Navigation Message, Global Positioning System (Vol I), Navigation, The Institute of Navigation, [1980].

S. Malys and Major P. Jensen
Defense Mapping Agency Systems Center / EG
6500 Brookes Lane
Washington D.C. 20315

(Received August 31 1989;
Revised ;
Accepted)

Paper number

Malys and Jensen : Geodetic Point Positioning

Malys and Jensen : Geodetic Point Positioning

Malys and Jensen : Geodetic Point Positioning

TABLE 1. Data Corrections and Their Functional Dependencies

Correction	Data Values	Surface Weather Obs.	A priori Position Estimate	Adopted Ephemerides/ Clock States
1. Epoch of Receipt to Epoch of Transmission	√			
2. Satellite Clocks				√
3. Receiver Offsets*				
4. Ionosphere	√			
5. Troposphere		√	√	√
6. General Relativity				√
7. Earth Rotation			√	√
8. Satellite Antenna Offsets			√	√

* The TI4100 frequency offsets of -6000 Hz and +7600 Hz are modeled away by adding 6000(Δt) cycles and subtracting 7600(Δt) cycles to/from the L_1 and L_2 recorded carrier beat phase respectively, where Δt represents the time interval (seconds) between the data value epoch and the current reference epoch for a particular satellite.

TABLE 2. Summary of CASA UNO Data Set Selection

Key to satellites used: a: PRN numbers 3,6,9,11,12,13 b: PRN numbers 3,6,9,11,12 c: PRN numbers 6,9,11,12,13 d: PRN numbers 6,8,9,11
e: PRN numbers 3,6,9,11,13 f: PRN numbers 3,6,11,12,13 g: PRN numbers 6,9,11,13

	Day of 1988 (each day contains 1 data set)																			
Station Name	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
CASA Area																				
Albrook Panama	a	f	a	a	a	a	a	a	a	c	a		a			a	a	a	a	
Baltra Ecuador							a	a	a	c	a	a								
Bucaramanga Columbia								d		d	e	e			e	e	e	e	d	
Cali Columbia	a			a				a	a	c	a	a								
Cocos Costa Rica		f	a	a	a	a	a	a	a	c	a	a	a		a		g		a	
Limon Costa Rica	a	f	a	a				a	a	c		a			a		a	a	a	
Extended Network																				
Blackbirch New Zealand	a	a	a	a	a	a	a	a	c	a	a	a	a		a	a	a	a		
Canberra Australia	a	a	a	a	a	a		a	a	a	a	a	b		b	a	a	a	a	a
Kokee US (Hawaii)	a		a	a	a			a	a		a	a								
Onsala Sweden		a							a										a	
Wettzell West Germany		a									a								a	

TABLE 3. Mean GASP-Estimated WGS 84 Point Positions

Station	Number of Data Sets	(a=6378137m, 1/f=298.257223563) Latitude			Longitude			Ellipsoid Height
Albrook	16	8°	59'	16.311"	280°	26'	30.145"	71.69m
Baltra	6	-0	27	38.410	269	44	27.910	61.70
Bucaramanga	9	7	7	0.863	286	49	5.613	1181.51
Cali	7	3	30	16.107	283	38	36.067	995.24
Cocos	15	5	32	51.311	272	57	17.206	143.48
Limon	12	9	57	52.530	276	58	23.833	13.55
Blackbirch	17	-41	44	42.813	173	48	20.104	1362.39
Canberra	18	-35	23	51.422	148	58	42.862	664.80
Kokee	8	22	7	34.518	200	20	6.315	1167.32
Onsala	3	57	23	43.071	11	55	31.891	47.94*
Wettzell	3	49	8	40.760	12	52	43.161	664.85*

*Ellipsoid height of TI4100 antenna L_1 phase center. All other ellipsoid heights are of the monument.

TABLE 4. Statistics From Repeated GASP Point Position Estimates

Station	Number of Data Sets	Standard Deviation of a daily point position* X	Y	Z	ϕ	λ	h
		all units are meters					
Albrook	16	.72	.73	.55	.57	.77	.67
Baltra	6	1.63	.64	.52	.52	1.64	.64
Bucaramanga	9	.68	1.13	.82	.75	.78	1.12
Cali	7	.98	.94	.82	.78	1.04	.91
Cocos	15	1.02	.93	.48	.46	1.03	.93
Limon	12	.83	.89	.55	.51	.87	.89
Blackbirch	17	.95	.83	.72	.38	.80	1.15
Canberra	18	.67	.74	.57	.30	.61	.92
Kokee	8	.32	.98	.49	.40	.93	.52
Onsala	3	.08	.07	.35	.24	.09	.27
Wettzell	3	.81	.93	.74	.68	1.06	.72

* The standard deviation of the mean components given in Table 3 can be obtained by dividing the values given here by the square root of the number of data sets used.

TABLE 5. Comparison of Point Positioning Results Obtained From the Adoption of Broadcast Versus Precise Ephemerides and Satellite Clocks

Ephemeris/Clock Source	Standard Deviation of a Daily GASP Point Position					
	X	Y	Z	ϕ	λ	h
	all units are meters					
Broadcast	1.59	1.20	1.22	1.21	1.65	1.13
NSWC Precise	.72	.71	.48	.57	.77	.67

* Standard deviation represents that of an individual component estimate. The standard deviation of a mean component is obtained by dividing by the square root of 16 (number of data sets used). Station: Albrook.

TABLE 6. Accuracy Assessment of GASP Geodetic Point Positions

Station	Independent Positioning Source*	Mean GASP Result - Independent Result all units are meters		
		$\Delta\phi$	$\Delta\lambda$	Δh
Albrook	TRANSIT	.13	-.24	-1.77
Onsala	NGS (CIGNET)	.48	.59	.51
Wettzell	NGS (CIGNET)	.73	1.11	1.12
Albrook	NSWC PT.POS.	.03	.03	-.32
Blackbirch	NSWC PT.POS.	.04	-.64	.03
Canberra	NSWC PT.POS.	-.09	-.78	-.07

* All comparisons were done on the WGS 84 ellipsoid.